GROWTH AND NUTRITION OF PINUS RADIATA ON A RECENT COASTAL SAND AS AFFECTED BY NITROGEN FERTILISER

I. R. HUNTER

Forest Research Institute, New Zealand Forest Service,
Private Bag, Rotorua, New Zealand

and G. F. HOY

New Zealand Forest Service,
P.O. Box 647, Palmerston North, New Zealand

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ABSTRACT

Two nitrogen fertiliser trials were established in nitrogen-deficient **Pinus radiata** D. Don growing on a recent coastal sand. Results after 5 years showed that nitrogen fertiliser induced a large increase in basal area growth, an increase in height growth, but no change in tree form. Foliar nitrogen concentrations were ephemerally increased by nitrogen fertiliser.

INTRODUCTION

Recent windblown sands are found along the west coast of the North Island of New Zealand. Most areas of such sand now carry *P. radiata* plantations, established primarily to stop sand movement inland. In preparing for afforestation, marram grass (*Ammophila arenaria* L.) is planted and yellow tree lupin (*Lupinus arboreus* Sims) sown (*see* Mead & Gadgil (1978) for recent review). The sands are naturally very low in nitrogen and the *P. radiata* relies on atmospheric nitrogen fixed by the lupin for its main supply of that nutrient. The foliar nitrogen concentrations of stands of *P. radiata* in these forests at 1.2–1.3% N (Forest Research Institute 1982) are, however, generally low (Will 1978).

Fertiliser trials have been rare on these sands. A factorial trial (complete fertiliser and lupin control) was established in young *P. radiata* at Woodhill Forest north of Auckland in 1968 (Jackson *et al.* in press). By the time the trees were 7 years old, foliar nitrogen concentrations in the control blocks averaged just less than 1.0% (Mead & Gadgil 1978). At age 13 the volume increment in the highest density plots was 40% of that in the comparable plots with lupin plus fertiliser. Frequent additions of fertiliser (in the absence of lupins) produced slightly better growth than that resulting from lupin alone. Dominant height was significantly improved in the plots with fertiliser.

In another similar trial in Woodhill Forest (Mead & Gadgil 1978) located on a naturally more fertile area of sand a similar pattern of response, although of less magnitude, was observed.

In 1975 areas of chlorotic foliage became very noticeable in closed canopy *P. radiata* in Santoft Forest – a forest on recent sands on the Manawatu coastline in the North Island of New Zealand. The visual symptoms were very similar to those illustrated in Fig. 3 of Will (1978). Those symptoms have been associated with nitrogen deficiency. After interpretation of black and white aerial photography, it seemed that approximately 25% of the central block of the forest was affected to some degree. More recently available computer-enhanced Landsat imagery (Hunter 1978) shows the extent and variation of the problem clearly (Fig. 1). The dark blue and purple areas in the central block indicate where the canopy has completely closed. Green to red tints occur where reflectance from sand below the canopy begins to dominate as a result of a progressively lighter tree canopy.

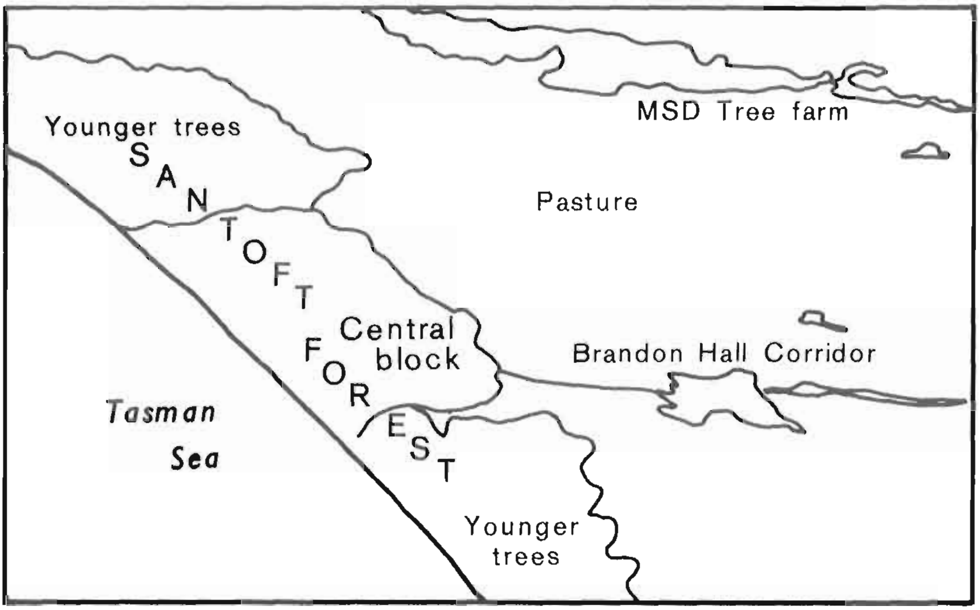
Two nitrogen fertiliser trials were established to attempt to correct the problem. One trial was in recently thinned moderately chlorotic 11-year-old *P. radiata.* A standard trial design, in which three rates of nitrogen were applied, was used. A background dressing of phosphorus was applied. One year later it was decided to extend the work to a more severely chlorotic area. In this new area some of the tree tops had begun to die back and generally leader extension had ceased. This symptom had not previously been linked with nitrogen deficiency. There was some doubt therefore that nitrogen fertiliser alone would correct the severe check observed at this site. The phosphorus application had had no visible effect on the degree of chlorosis in the control plots at the moderately chlorotic site and was therefore omitted from this trial.

METHODS AND MATERIALS

Site Description and Plot Layout

The moderately chlorotic stand had been planted in 1964 with approximately 2240 stems/ha. It was managed on a normal, sand forest, fence-post-thinning regime, and 297 stems/ha were progressively pruned to a height of 6 m by 1973. In 1974–75 the stand was thinned for posts to 477 stems/ha. After thinning the tree canopies were sparse relative to other areas in the forest and foliage was a light green in colour. The normal resurgence of lupin from buried seed was allowed to occur.

Twelve 0.21-ha plots were established in early spring 1975. Trees in an inner measurement plot of 0.09 ha had a paint band applied at breast height. Plots of similar initial basal area were grouped into three blocks of four plots. Within each plot the following treatments were assigned at random: control (no fertiliser), nitrogen at 100 kg/ha (N100), 200 kg/ha (N200), and 300 kg/ha (N300). Fertiliser was applied to the whole plot by hand as calcium ammonium nitrate (23% N) in September 1975. As sometimes occurred in trials using this common design, a basal dressing (of 75 kg P/ha as superphosphate) was applied to all plots at the same time. No other treatment was applied to either encourage or discourage normal lupin recolonisation of the site after thinning.



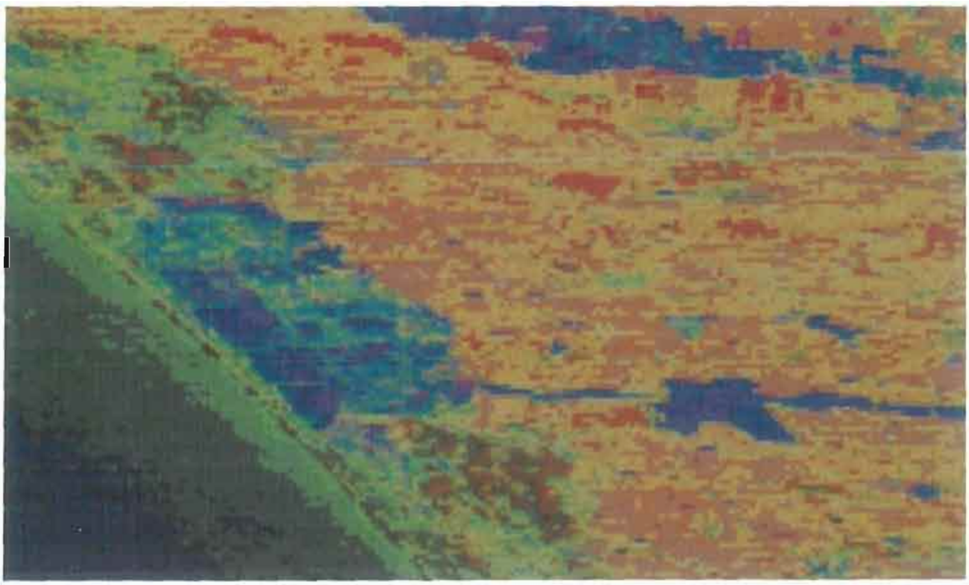


FIG. 1—Landsat image of Santoft Forest showing nitrogen-deficient areas (green and yellow tones) and non-deficient areas (blue-purple tones) in the central block. The main features in the photograph are indicated in the Key (NASA No. 2299-21183, 17.11.75)

Trees on the severely chlorotic site had been planted at 2400 stems/ha in 1963, and 755 stems/ha were pruned to 2.5 m in 1970–71. There had been no thinning and very little tree mortality to 1975. At the time of trial establishment trees growing on this site carried very light canopies with markedly yellow-green foliage. In most of the trees leader extension had been small in the previous 3 to 5 years and in a very few trees the leader had died back by up to 0.3 m. Dead lupin stems were visible in the trial area, but in the forest generally the lupin present at tree planting tends to die out by tree age 5. If the pattern of lupin growth at this site was similar there would have been no living lupin in the area for at least 8 years prior to trial establishment. No lupins became established during the life of the trial.

At this site, in order to restrict the experiment to an area of equal and severe chlorosis, only five plots of 0.08 ha with an inner measurement plot of 0.04 ha could be established. Two of the plots were left without fertiliser and three received 400 kg N/ha applied by hand in 100-kg-N/ha doses at 3-monthly intervals from September 1976. The first two applications were of calcium ammonium nitrate, the second two of sulphate of ammonia.

All trees at both sites were measured for breast height diameter initially and annually in winter, and a six-tree sample of tree heights was recorded at the same time. Measurements were entered in the Permanent Sample Plot System (McEwen 1979). A covariance analysis was made of plot mean height and basal area, with the initial measurement as covariate, using Genstat (Lawes Agricultural Trust 1980). Linear and quadratic effects of fertiliser rate were examined in the trial comparing application rates. Plot volume was calculated from a common tree volume equation by the PSP system.

Tree Form Factor Assessment

In 1980 at the moderately chlorotic site five trees were felled per plot and measured for diameter and bark thickness at intervals of less than 3 m along their stem. From these sections total tree volume (under bark) was calculated. Form factor (the ratio of tree volume to the volume of a cylinder with the same total height and a diameter equal to tree breast height diameter) was calculated. Form factors were further processed by analysis of variance and then, because form factor is related to tree size (Barker 1978), by analysis of covariance on breast height diameter.

Nutrition

Soil sampling and analyses

Forty 25-m cores from the top 10 cm of mineral soil were taken from each control plot and combined to provide one sample for each site. Soils were analysed for percentage of sand (Piper 1950), pH (Blakemore *et al.* 1972), percentage of nitrogen (Searle 1974), Bray phosphorus (Bray & Kurtz 1945), and Bray cations (Ballard 1978).

Foliage sampling and analyses

Foliage was collected in autumn at approximately 2-yearly intervals. Seven to 10 dominant and codominant trees were visited in each plot at both sites and first-year foliage was collected from the upper crown. Samples were oven-dried at 60°C to constant weight.

For nitrogen, phosphorus, potassium, calcium, and magnesium, ground samples were digested using sulphuric acid and hydrogen peroxide in the presence of lithium sulphate and selenium (Parkinson & Allen 1975). Nitrogen was determined by the indophenol-blue method and phosphorus by the vanadomolybdate method. Potassium, calcium, and magnesium were determined by atomic absorption (Nicholson, in press).

For analyses of manganese, iron, zinc, copper, and boron, foliage samples were ground, dry-ashed, dissolved in hydrochloric acid, and the respective concentrations determined by atomic absorption (Nicholson, in press).

Litter weight and nutrient content

At the severely chlorotic site in autumn 1981 litter was collected at five randomly selected points in each plot using a 0.25-m^2 sampling frame. In the control plots litter was sparse and dry, in the plots with fertiliser it was slightly thicker, but in both sets of plots it separated easily and completely from the soil surface and there was no sand contamination. Litter weights per hectare were calculated from dried litter samples. Litter was analysed for nitrogen using the same methods as for foliage, and the nitrogen content of the litter was calculated.

RESULTS

Results of soil analyses are shown in Table 1. Results of foliage analyses for the moderately chlorotic site are given in Table 2, and for the other site in Table 3. Fertiliser application was followed by a rapid (within 6 months) improvement in foliage colour, and the amount of foliage also appeared to increase. These differences remained noticeable for at least 3 years at the moderately chlorotic site and for 4 years at the other site.

TABLE 1—Soil nutrient and physical analyses for two sites

Site	Sand (%)	pH	N (%)	Bray P (ppm)	Bray cations (me %)		
					Ca	Mg	K
Severely chlorotic	98	6.9	0.01	28	23	0.65	0.06
Moderately chlorotic	98	6.9	0.02	29	17	0.69	0.04

TABLE 2—Effect of different rates of nitrogen fertiliser on foliar nutrient concentrations at the moderately chlorotic site in the presence of over-all phosphorus fertiliser (means of three plots)

Treatment	1976 (+ 1 year)	1977 (+ 2 years)	1979 (+ 4 years)					
	N (%)	N (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)
Control	1.0	1.1	1.1	0.15	0.74	0.24	0.14	36
N100	1.4	1.0	1.2	0.15	0.70	0.25	0.14	33
N200	1.4	1.1	1.2	0.16	0.85	0.25	0.16	33
N300	1.8	1.1	1.1	0.16	0.72	0.17	0.14	36

TABLE 3—Effect of nitrogen fertiliser on foliar nutrient concentrations at the severely chlorotic site (means of two or three plots)

	N	P	K	Ca	Mg	Mn	Fe	Zn	Cu	B
	(%)					(ppm)				
Plots treated with 400 kg N/ha										
1977 (+ 1 year)	1.25								2.4	11
1979 (+ 3 years)	1.02	0.13	0.73	0.23	0.15		43			
1981 (+ 5 years)	0.87	0.09	0.62	0.19	0.18	76		30	3.1	
Untreated plots										
1977 (+ 1 year)	0.60								2.4	17
1979 (+ 3 years)	0.74	0.10	0.50	0.53	0.19		50			
1981 (+ 5 years)	0.73	0.09	0.77	0.40	0.17	142		38	3.3	

The three treated plots at the severe site had 4.13 t litter/ha containing 24.5 kg N, while the plots without fertiliser had 1.82 t litter/ha and 10.2 kg N.

Tables 4 and 5 show the effect of nitrogen fertiliser on basal area and mean height at the moderately chlorotic site. The effect on mean top height (height of the 100 largest-diameter trees/ha) was similar to the effect on mean height but smaller, with a much lower level of statistical significance. In 1980 the difference between mean top height in the control and in N300 was 0.9 m.

TABLE 4—Effect of rates of nitrogen on basal area (m^2/ha) at the moderately chlorotic site (adjusted by covariance on 1975 basal area)

Treatment	Year (and years since fertiliser application)					
	1975 (0)	1976 (+ 1)	1977 (+ 2)	1978 (+ 3)	1979 (+ 4)	1980 (+ 5)
Control	11.9	12.8	14.9	16.7	19.5	21.5
N100	11.9	13.8	17.0	19.2	22.1	24.2
N200	11.9	14.3	18.0	20.7	24.4	26.6
N300	11.9	14.4	18.4	21.5	25.0	26.9
Statistical significance						
Nitrogen treatment		***	***	***	***	***
Linear effect of rates		*** +ve	*** +ve	*** +ve	*** +ve	*** +ve
Quadratic effect of rates		* -ve	* -ve	? -ve	? -ve	? -ve

*** $p < 0.001$

** $p < 0.01$

* $p < 0.05$

? $p < 0.10$

+ve Increasing effect across rates of fertiliser

-ve Negative effect across rates

TABLE 5—Effect of rates of nitrogen on mean height (m) at the moderately chlorotic site (adjusted by covariance on 1975 mean height)

Treatment	Year (and years since fertiliser application)					
	1975 (0)	1976 (+ 1)	1977 (+ 2)	1978 (+ 3)	1979 (+ 4)	1980 (+ 5)
Control	12.6	13.6	14.4	15.4	16.6	17.8
N100	12.6	13.6	14.7	15.8	17.2	18.3
N200	12.6	13.7	15.0	16.2	17.9	18.9
N300	12.6	13.7	15.0	16.6	18.5	19.6
Statistical significance						
Nitrogen treatment		NS	***	*	***	*
Linear effect of rates		? +ve	*** +ve	*** +ve	*** +ve	*** +ve
Quadratic effect of rates		NS	NS	NS	NS	NS

*** $p < 0.001$
** $p < 0.01$
* $p < 0.05$
? $p < 0.10$
NS Not significant
+ve Increasing effect across rates of fertiliser
-ve Negative effect across rates

Figure 2 shows the annual basal area increment by treatments as a percentage of basal area growth in the control and indicates that the fertiliser effect had apparently culminated by 1980.

There was no significant effect of fertiliser treatment on form factor either with or without the use of diameter as a covariate. The standard error of a difference in the covariance analysis was equivalent to 2.9% of the mean form factor. The volumes calculated by the Permanent Sample Plot system are therefore an unbiased estimate of relative volume responses to fertiliser rates and indicate a gain of 20, 40, and 50 m^3/ha to N100, N200, and N300 respectively.

Tables 6 and 7 show the effect of fertiliser on basal area and mean height at the severely chlorotic site. The effect on mean top height was of similar magnitude to that on mean height. Volume gain by 1980 was estimated at 70 m^3/ha and annual growth increment in the treated plots still exceeds that in the control plots.

TABLE 6—Effect of nitrogen fertiliser on basal area (m^2/ha) at the severely chlorotic site (adjusted by covariance)

Treatment	Year (and years since fertiliser application)					
	1976 (0)	1977 (+ 1)	1978 (+ 2)	1979 (+ 3)	1980 (+ 4)	1981 (+ 5)
400 kg N/ha	18.3	21.5	24.9	28.8	32.2	34.7
No fertiliser	18.3	19.2	20.3	21.1	22.0	22.5
Significance		**	**	***	***	***

*** $p < 0.001$
** $p < 0.01$

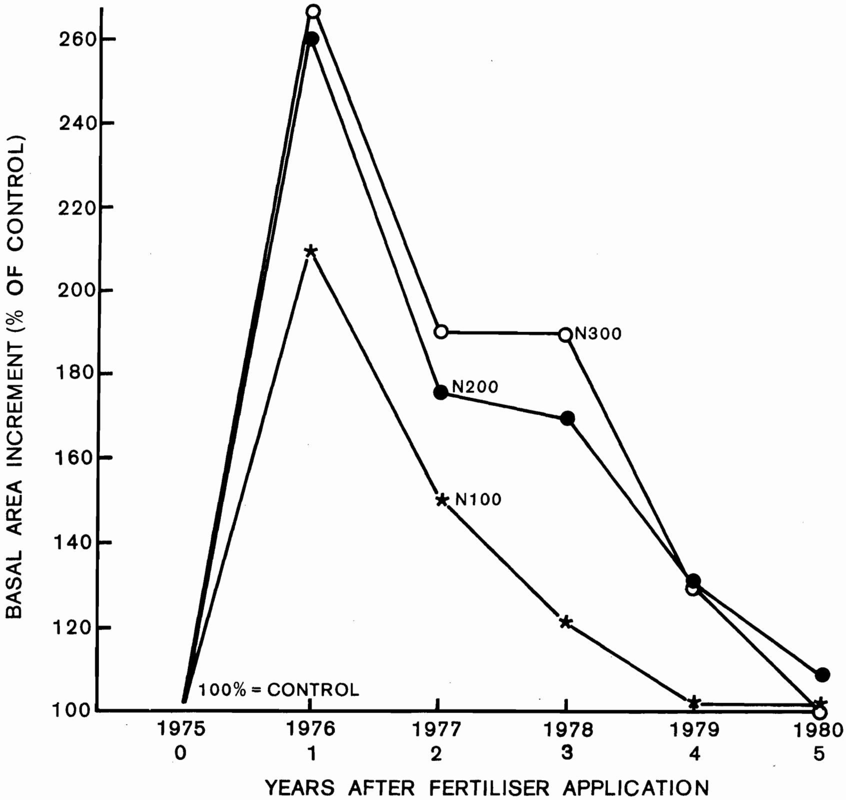


FIG. 2—Annual basal area increment in fertilised plots (by treatment) as a percentage of the control plot at the moderately chlorotic site.

TABLE 7—Effect of nitrogen on mean height (m) at the severely chlorotic site (adjusted by covariance)

Treatment	Year (and years since fertiliser application)					
	1976 (0)	1977 (+ 1)	1978 (+ 2)	1979 (+ 3)	1980 (+ 4)	1981 (+ 5)
400 kg N/ha	8.0	8.6	9.7	10.7	12.0	12.7
No fertiliser	8.0	8.4	8.7	8.8	9.0	9.1
Significance		NS	NS	?	*	*

* $p < 0.05$

? $p < 0.10$

NS Not significant

DISCUSSION

Soil analysis showed that the soils of the two sites were fairly similar. Marked differences in the size of trees and state of chlorosis between the sites could have been due to the success or otherwise of initial lupin establishment.

At the moderately chlorotic site where there was a basal dressing of phosphorus fertiliser, foliage analysis showed that only nitrogen concentrations were low. Foliar phosphorus concentrations would probably have been adequate without the basal phosphorus dressing since the average concentration for a sample of untreated plots drawn from throughout that area was 0.14% (Forest Research Institute 1982). The phosphorus concentration in a control plot completely without fertiliser in another trial immediately adjacent was 0.15% (unpubl. data).

At the very chlorotic site foliage analysis indicated an extremely low nitrogen and a low phosphorus status (Will 1978). Phosphorus deficiency would not normally be expected in soil with a Bray P of 28 ppm. Since the phosphorus concentration increased after fertiliser application, the nutrition of the trees was probably considerably disordered by the extreme and overriding deficiency of nitrogen. Interpretation of the level of other elements is therefore difficult. However, limited areas of low phosphorus concentration are found associated with low nitrogen in the forest (unpubl. data) and the role of phosphorus in nutrition at Santoft possibly needs further study.

Addition of nitrogen fertiliser caused an increase in foliar nitrogen at both sites. In the rates trial, although nitrogen concentrations fell to the same acutely deficient level as the control within 1 year of application, growth response (Fig. 2) continued for several years. At the other site (Table 3) the decline in foliar nitrogen in subsequent years was not as rapid: even after 5 years there was a slightly higher concentration in the treated plots than in the control. However, at no time did the concentration rise above the previously determined (Will 1978) deficiency level. The litter weight figures are an indirect but objective indication that during the years of the experiment more foliage was produced by the trees with fertiliser (the alternative explanation that turnover of this litter is proceeding more slowly is much less likely in view of its slightly higher nitrogen content) and support the visual impression that the trees which had received fertiliser carried more foliage. Thus it appears that the foliage response to nitrogen fertiliser was expressed in terms of needle growth rather than needle nitrogen concentration.

Addition of nitrogen fertiliser at the severely chlorotic site reduced foliage calcium, boron, and manganese content, although the changes were not from or to a level thought likely to affect nutritional health (Will 1978). Therefore, nitrogen deficiency was mainly responsible for the symptoms observed at the severely chlorotic site and the addition of nitrogen fertiliser alone has been sufficient to greatly improve growth for at least 5 years. The litter analysis was undertaken partly to see whether the accumulation of nitrogen in the litter could be responsible for the gradual decrease in tree foliage nitrogen concentration. However, the difference (14 kg N/ha) between plots with and without fertiliser is so small that this seems unlikely to be more than a contributory reason.

An increase in basal area in excess of 5 m^2/ha resulted from 200 kg N/ha at the moderately chlorotic site, and 12 m^2/ha from 400 kg N/ha at the severely chlorotic site.

These responses overlap those obtained in the two Woodhill trials described earlier. They are as large as or larger than those obtained in several trials in Kaingaroa (Mead & Gadgil 1978) where average foliar nitrogen concentrations are approximately 1.4% (Forest Research Institute 1982). It appears therefore that there is a broad relationship between degree of nitrogen deficiency and amount of response to nitrogen fertiliser. Crane (1981) reported a similar relationship for *P. radiata* in Australia.

Woollons & Will (1975) stressed that on the pumice plateau (including Kaingaroa) responses to nitrogen without thinning were unlikely. Moreover, for every year of delay after thinning the response to nitrogen decreased. At Braeburn in Nelson, however, a 40-year-old stand with a foliar nitrogen of 1.1% before fertiliser application responded strongly to nitrogen fertiliser applied 7 years after thinning (Mead & Gadgil 1978). On the strongly chlorotic site at Santoft, a dense unthinned 13-year-old stand responded very strongly. The degree of nitrogen deficiency is an important extra condition in determining whether a stand will respond to nitrogen fertiliser without thinning.

Increases in height growth resulting from nitrogen fertiliser application were reported by Mead & Gadgil (1978) for the previously mentioned 40-year-old Nelson stand. However, a younger stand (14 years old), also in Nelson, reported by these authors with a marginally higher foliar nitrogen status (unpubl. data) showed no change in height growth. Woollons & Will (1975) said that there is no height response on the pumice plateau.

At the moderately chlorotic Santoft site, height response in percentage terms was less than basal area response, whereas at the severe site percentage height and basal area response were equal. Thus it may be that height growth is slightly less affected by nitrogen deficiency than basal area growth. In that case a height response would be predicted for very deficient crops (i.e., less than 1.2% foliar N) but not for those that are marginally deficient (i.e., approximately 1.4% N) for maximum basal area growth. Miller *et al.* (1981) have detected a similar pattern of response in *Pinus nigra* var. *maritima* (Ait.) Melv.

Woollons & Will (1975) reported changes in tree form after nitrogen fertiliser application on the pumice plateau. Mead & Gadgil (1978) reported that the 40-year-old Nelson stand changed in tree form but that other stands, including one on the pumice plateau, did not. In interpreting these and other reports, Barker (1978) felt that a form change after fertiliser application would depend on the density of the crop and that fertiliser after heavy thinning should be accompanied by a large positive change of form factor. The Santoft rates trial satisfied those conditions yet there was no positive change of form factor, differences being non-significant and means in the plots with fertiliser less than in the control.

In deciding where to invest money in nitrogen fertiliser application one of the relevant criteria is the magnitude of the response. Recent trials on the pumice plateau where trees generally are naturally more productive than on coastal sands have indicated average responses to nitrogen fertiliser of 30–40 m^3/ha (R. C. Woollons, pers. com.). The responses reported here at 40 and 70 m^3/ha are as large as this or larger and indicate that applying fertiliser to the sand dune forests is a potentially useful way to increase the over-all wood flow.

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